Multi-agent system with iterative auction mechanism for master bay plan problem in marine logistics

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Abstract:

The support of containerization to trade development demands an efficient solution method for the container loading problem in order to reduce shipment and handling time. Hence, the stowage planning of containers is critical to providing speedy delivery of resources from the area of supply to the area of demand. Moreover, information on container terminal activities, structure of ship, and characteristics of containers is distributed among stowage planners. This information imposes constraints, and so the master bay plan problem (MBPP) becomes NP-hard. Therefore, a multi-agent systems (MAS) methodology is designed to effectively communicate the information and solve the MBPP sustainably. In the designed MAS methodology, an information exchange system (IES) is created for stowage planners to bid for ship slots in each experimental iterative combinatorial auction (ICA) market. The winner in the ICA experiments is provided with the ship slots, and the entire bay plan is prepared. Further, the ship-turnaround time is validated using the data obtained from the benchmark problem of Wilson and Roach (1999).

Keywords: Master bay plan problem (MBPP), multi-agent system (MAS), information exchange system (IES), iterative combinatorial auction (ICA).

1. Introduction

Since the advent of standard containers, trade has increased severalfold as containerization has facilitated the intermodal transport of goods, short sea shipping, expansions in ship size, and competitiveness (Lun et al., 2010). Therefore, it is necessary to effectively manage the complex activities, such as loading, storing, and unloading processes, to reduce ship turnaround time, handling charges, and transit time along the container distribution system during certain and uncertain events and to improve the economic performance of liner shipping companies (Imai et al., 2006; Shi and Li, 2016). Hence, the effective arrangement of containers, that is, the stowing of containers in ships, is the key to achieving higher productivity and economic gain. Stowage planning involves the allocation of set C of A_{xyz} containers of different types into a set SA of $L_{i,j,k}$ available locations within a container ship, considering structural and operational constraints related to both the containers and the ship, and minimizing the total stowage time or ship turnaround time (t_L) (Ambrosino et al., 2004). Thus, generating an optimal stowage plan—considering the size, weight, destination, stability, and assignment constraints and the combinatorial nature of mapping ship slots to the containers—is critical for the success of liner shipping companies (De Queiroz and Miyazawa, 2013; Keceli, 2016).

As container stowage planning involves several constraints, MBPP is NP-hard and so is solved by skilled personnel using heuristic procedures discussed by Woo et al. (2013) and Yun and Choi (1999). Also, the information regarding the stowage activities is scattered among stowage planners without an information exchange mechanism to solve MBPP (Huang et al., 2016). Moreover, the result obtained from the empirical model developed by Lu et al. (2016) pointed out that effective communication and collaboration among terminal users is the key to improving container terminal sustainability performance. Hence, the design of an effective information exchange system (IES) is crucial to making sustainable decisions in stowage planning (Partibaraj et al., 2015). UNCTAD (2013) also indicated that sustainable development depends on the linkages between economic, social, and environmental aspects in the decision support system. Further, the application of the complex adaptive system by Justice et al. (2016) provided scope for port managers (agents) to self-organize, assist in better managing ports, and achieve sustainability. In addition, the use of the multi-agent system (MAS) concept in container terminal management by Henesey et al. (2002) supported its application, and highlighted that auction as an information protocol among agents is important for its implementation. Therefore, an auction mechanism is used to successfully implement MAS methodology to the MBPP.

As per the study of different types of auction by Kalagnanam and Parkes (2004), it is revealed that the auction mechanism faces issues on incentive compatibility among agents in disclosing the private information on allocation. The study also concluded that an efficient allocation rule to maximize the total utility of agents and the Vickrey-Clarke-Groves (VCG) payment rule to handle the incentive compatibility problem are vital. In the VCG payment rule, the incentive compatibility problem is solved by promoting the truth, revealed as a dominant bidding strategy for agents in an auction. It avoids the incentive for bidders in the auction to lie about the valuation of resources. Also, the externality placed on the other agents in the system by the reported preferences of the winning agent in the auction is calculated as the VCG payment to promote truthful bidding. An example of calculating the VCG payment is presented in Appendix 1. To further ease the computational and communicational difficulty in the VCG mechanism, an iterative variant of the VCG combinatorial auction designed by Debasis (2011) is used to allocate the combination of identical goods (containers). In general, iterative auction starts from zero and continues based on the bids submitted by agents to reflect its interest in ship slots, until exactly one agent is interested at the competitive equilibrium (CE) price of the auction market. The universal competitive equilibrium (UCE) means the equilibrium price that satisfies the property so that if any one agent is removed from the current auction market, the equilibrium price remains the same for the new version of the current auction market. Thus, the paper develops a multi-agent system (MAS) approach with ICA and VCG payment rules to assist stowage planners in communicating with IES, and solves the MBPP sustainably. A software program is developed to completely enumerate the bids submitted by agents to the ICA with the VCG payment rule to solve the MBPP and implement MAS methodology.

In the designed MAS methodology, the operators involved in stowage planning are formed as agents to communicate with the IES by bidding based on the redemption value set by the auctioneer (ship captain) for each set of bundled slots. In turn, the IES forms market experiments to solve the MBPP using ICA. The experimental market design considers the agents with zero intelligence on bidding in the ICA mechanism, competitive equilibrium pricing, allocation policy, and continuous clearing policy of the auction market after every allocation at CE price. Zero-intelligence agents are agents who do not seek to maximize profit and do not observe, remember, or learn. A set of experiments with the above market policy is conducted to allocate each set of bundled slots. The desired allocation in an experiment is chosen by the experimenter (IES) among each set of experiments. The results are obtained and consolidated to prepare the master bay plan. Finally, the container total stowage time for the master bay plan is calculated and validated with the instances of the benchmark problem by Wilson and Roach (1999).

The rest of the paper is organized as follows: Section 2 reviews past relevant studies, Section 3 describes the MBPP, Section 4 explains the design of the MAS model and its methodology, Section 5 provides the numerical evaluation of the MAS model, Section 6 presents the results and compares the solutions using the benchmark problem, and Section 7 summarizes our study with future scope.

2. Literature review

The research contributions related to the master bay plan problem, the extent usage of MAS, and the development of auction mechanisms discussed in the literature to automate stowage planning processes are reviewed in this section. A few attempts to model the MBPP are as follows. The earliest attempt by Botter and Brinati (1992) was to develop a mathematical model, and they explained the computational complexities in determining an optimal solution at a reasonable processing time. Subsequently, to minimize the total stowage time, Ambrosino et al. (2004) explained the MBPP settings and proposed a 0-1 linear programming model with sophisticated pre-processing and pre-stowing heuristics. Furthermore, Ambrosino et al. (2006) proposed a local search exchange algorithm for removing solution infeasibilities to reduce the total stowage time by partitioning ship space using a branch and bound algorithm and allotted containers to each ship partition using a 0-1 linear programming model. In terms of considering other factors, Imai et al. (2006) formulated a multi-objective simultaneous stowage planning model considering ship stability, list, trim, and container re-handle, and reported that the computation time to obtain a set of non-inferior solutions is huge. The difficulty of solving the NP-hard combinatorial master bay plan problem was explained by Sciomachen and Tanfani (2007) using three-dimensional bin packing heuristics. In terms of solution techniques, Dubrovsky et al. (2002) developed a compact encoding technique to reduce the solution search space using a genetic algorithm and constructed a stowage plan for ships with a capacity up to 1,000 TEUs. Wilson and Roach (1999) applied local search algorithms and techniques based on combinatorial optimization for solving the container stowage process in two phases, i) a strategic phase to assign generalized containers to bays, and ii) a tactical planning phase to assign specific locations in a block to specific containers. Previous studies on modeling and solution techniques show that different attempts have been made in developing suitable automated solution techniques to the stowage planning process. However, full automation of the stowage planning process is not yet addressed, hence, the assistance of the full-fledged decision support system to automate the stowage activities is essential.

A few automated decision support solutions are reviewed in this section. Douma et al. (2012) designed a simulation game for implementing a multi-agent system among independent and competitive actors in barge handling and terminal operations. The game supports its implementation with challenges to design a game in unstable network connections. The importance of sharing critical information and incentives for parties to accept performance-based pricing mechanisms is discussed in the recent studies (Lam and Zhang, 2014; Lam and Yip, 2008; Arul et al., 2006). Recent studies also showed that a well-organized administration, a sound financial system, and competitive policies considering the effect of information exchange on coalition models could promote sustainability (Marlow and Nair, 2006; Wang et al., 2016). Sinha-Ray et al. (2003) proposed MAS application to achieve sustainability in international trade, container distribution, and inland distribution systems. Parsons and Wooldridge (2002) presented the interactions between MAS and game theory, with scope on designing efficient algorithms to handle the computational complexities. The application of game theory for MAS provides optimal solutions, but also provides negativities due to its design. However, the suggestion by Henesey et al. (2002) to design multi-agent architecture for allocating terminal resources and to develop an auction protocol for MAS implementation turned our interest to the review of auction mechanism design. Kalagnanam and Parkes (2004) presented the desired economic properties and the computational complexities in auction mechanism design. Debasis (2011) surveyed the optimal and economically efficient auction designs and described a particular iterative combinatorial auction that implements the VCG mechanism. Furuhata et al. (2009) presented an experimental approach to design and evaluate the market mechanisms with different sets of market policies. Similarly, the potential use of agent-based systems for logistics applications was highlighted in a recent review article by Min (2010). Hence, it is evident from the review that an integrated multi-agent system with an auction mechanism to solve MBPP has not been addressed so far, and it is a major gap that this study attempts to solve. Based on the review, it is obvious that MAS with an auction mechanism could be a potential solution approach to MBPP. Hence, the work attempts to design MAS and develop a software program with complete enumerative search algorithm of ICA to implement the MAS.

3. Description of the master bay plan problem

This section presents the objective criteria, the structural constraints of a container ship, containers, and their operational constraints in MBPP with its solution difficulties and assumptions.

3.1. Objective criteria

The objectives of this study are:

- To minimize the ship turn-around time at the container terminal.
- To design an IES for agents to share information regarding constraints in stowage planning.
- To assist the agents in actively participating in stowage planning by presenting its interest in

the form of bids to IES.

- To make sustainable decisions by efficient allocation of slots to agents involved in stowage planning activities.

3.2. Structural constraints of a container ship

The ship has specifications related to the structure, size of lower and upper decks, and type of the container ships. To understand its general arrangement and outline plan, the Lo-Lo (Lift on–Lift off) container ship that loads and unloads containers from the top using quay cranes (QC = 1 to nq) at transfer time (TT_H, QC) for movement between hatches (H = 1 to h) is considered, as shown in Figure 1. It exposes the structure and the available locations of cell with an 8-foot height, 8-foot width, and 20-foot length by using three two-digit indices. These indices generally represent:

- Bay (i = 1 to B), which gives its position relative to the cross-section of the ship (counted from bow to stern), where each 20-foot bay is numbered with an odd number, i.e., bay 01, 03, 05, etc., and two contiguous odd bays as one even bay for the stowage of 40-foot containers, i.e., bay 04 = bay 03 + bay 05. The bays are either above deck or below deck (enclosed within the ship beneath removable hatch-lids) and are grouped together using the associated hatch number.
- Row (j = 1 to R), which gives its position relative to the vertical section of the corresponding bay (counted from the center to the outside) ship locations represented by an even number if they are located on the seaside, i.e., row 02, 04, 06, and an odd number if they are located on the yard side, i.e., row 01, 03, 05, etc.
- Tier (k = 1 to T), which gives its position related to the horizontal section of the corresponding bay (counted from the bottom to the top) of the ship, that is, the levels are numbered from the bottom of the hold to the top with an even number, i.e., tier 02, 04, 06, etc., while in the upper deck, possible numbers are 82, 84, and 86. However the address numbers denoted for each ship location depend on the system adopted by the maritime company.

3.3. Container and its related constraints

The containers conforming to the International Organization for Standardization (ISO) standards are considered, and their dimensions are:

- Size of a container (z). Standard sizes of a container are 20 and 40 feet in length with a cross-section of 8 feet by 8 feet, expressed in terms of TEUs (Twenty-foot Equivalent Units). A 40-foot container is equivalent to two 20-foot containers and it restricts stowing a 40-foot bay if the corresponding two 20-foot slots are occupied.
- Type of container (x). Standard 20- and 40-feet containers (x = T, F) are stowed depending on size; however, the reefer (x = R_f) and hazardous (x = H_z) containers posses the exact location defined by the ship coordinator according to the provisions on the ship.
- Weight of container (Wy). The standard weight of an empty container (y = E) ranges from 2 to 3.5 tons, while the maximum weight of a full container (y = FL) to be stowed in a container

ship ranges from 20 to 32 tons for 20-foot and 30 to 48 tons for 40-foot containers, respectively. This load variation of full load, less than full load (y = LFL), and empty containers restricts the stowage concerning ship stability.

3.4. Operational constraints

The parameters considered in balancing the uneven distribution of load and stability of the ship are:

- Trim that reflects the angle of the vessel fore to aft must be close to zero or a desired value based on shipping line requirement.
- Heel that measures the inclination from the vertical towards port or starboard of the ship must be close to zero or a desired value based on shipping line requirement.
- Bending moment due to the forces acting from bow to stern must be close to zero or a desired value based on shipping line requirement.
- Torsion due to the forces acting from port to starboard produced by unevenly distributed cargo weight can weaken the physical structure of the ship.
- Over-stows due to the unloading of containers that block access to others must be avoided.
- Rehandle to move the containers and allow access to the unloading containers must be avoided.

The total weight of all containers cannot exceed the maximum ship capacity (Q). The weight of a stack in a tier with three 20-foot and 40-foot containers cannot be greater than the a priori established value provided by the shipping line. The weight of a container located in a tier cannot be greater than the weight of the container located in a lower tier having the same row and bay.

In addition, the stowage practices followed in the container terminal impose constraints for the speedy handling of containers using the allotted number of cranes, which impose additional constraints on hatch, block, and tier allocation of the ship to the containers. They are:

- Container arrangement in hatches: The bay partitioning practices followed according to the container destination are for the containers belonging to the first destination along the ship route. The priorities in bay allocation are B/2, B/2+3, B/2-3, B/2+4, B/2-4, B/2+5, and so on, and for next destination the priorities are B/2+1, B/2-1, etc., and continued for all bays and container destinations.
- Container arrangements in block: The rules for arranging containers in blocks are for the arrangement in central blocks to stack upwards from stern to bow and from the center toward the end; for starboard blocks, the sequence is to stack upward, stern to bow, and left to right; and for the port side, the sequence is to stack upward, stern to bow, and right to left.
- Container arrangement in tier: The stowing condition in tiers is to load first in lower tiers the containers having final destination of the ship and load last the containers to be unloaded first.
- Distribution of container: The equilibrium conditions required for safe transport are cross-equilibrium, that is, the weight on the right side of the ship, including the odd rows of the hold to carry heavy containers and upper deck, must be equal or within a given tolerance to the

weight on the left side of the ship, including the even rows of the hold and upper deck; horizontal equilibrium, that is, the weight on the stern must be equal or within a given tolerance to the weight on the bow; and vertical equilibrium, that is, the weight on each tier must be greater or equal than the weight on the tier immediately over it.

- Crane intensity: The safety distance that is two to six bay lengths between two adjacent operating cranes must be maintained because of the physical size of quay cranes.

These constraints make the MBPP problem difficult to solve due to the reasons presented in following section 3.5.

3.5. Problem size and difficulties

The container loading problem is combinatorial explosive with the number of possible stowage configurations; say, for a medium-sized container ship of 2,000 TEU, it is approximately 3.3 x 10^{5735}. Even for the smallest vessel sizes, container stowage planning is a large-scale problem due to the large number of variables. The characteristics prevailing in the maritime logistics on the stowage planning of containers imposes additional constraints on achieving reduced turnaround time. Thus, the problem has been described as being NP-hard by Botter and Brinanti (1992), who concluded that it is not possible to guarantee an optimal solution for commercial-sized ships in a reasonable processing time. Hence, the efficient ICA mechanism for MAS model is designed for agents involved in MBPP with the following assumptions.

3.6. Assumptions

- The interaction between the agents and ship coordinator is allowed only through IES.
- The demand for ship slots is assumed to be lesser than or equal to the number of available ship slot locations.
- The shipment demand (D) is bundled for combinatorial auction as follows: n steps are assumed and containers with D/n size are formed in each stage, m identical bundles of size n/m containers are assumed, and 2^m bundle sets (BS) are made to obtain bid requests from bidders in ICA.
- A 20-foot container is assumed as one TEU, and a 40-foot container as two TEUs.
- The ship turnaround time is considered equal to stowage time.
- The cycle port rotation for the ship is considered.
- Ballast control to maintain the stability of the ship is assumed to be set by the user and is neglected in the stowage planning process.
- Bids are assumed to be randomly generated from the uniform distribution by zero-intelligence agents in each experimental auction market created by IES.
- Agents in experiments are assumed to redeem all the bundles allocated to them at the end of each experiment.

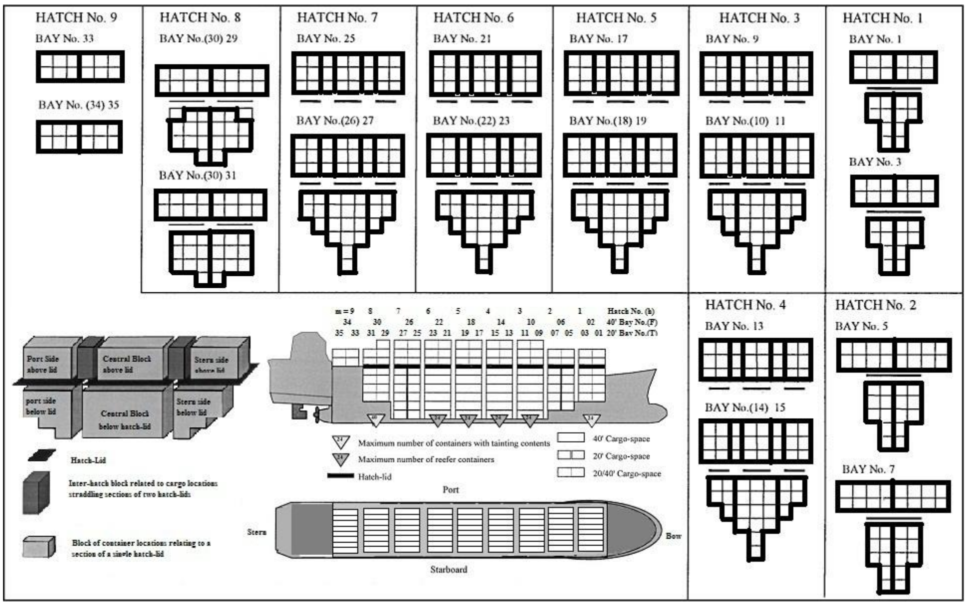

Figure 1: General arrangement, outline plan, and block formation for the Lo-Lo containership

4. Decision support system

The procedure to solve the MBPP using the MAS model and ICA mechanism are discussed in this section.

4.1. Design of MAS model

The MAS design phase consists of three stages to allocate containers in hatches, blocks, and tiers. The information implicit with agents and information exchange system (IES) in each of the stages is presented as follows:

4.1.1. Stage 1 – Hatch allocation to cranes

At this stage, the hatches are allocated by IES based on the output of the experiment conducted, using the redemption value of the hatch bundles formed from available hatch capacity. The redemption values are set by the ship captain to implicitly inform the ship's stability condition and its structural restrictions. The IES runs experiments in the market designed with ICA mechanism and provides an information exchange mode to crane agents. Based on the information from IES, the crane agents submit the preferences in the form of bids and demand hatches. The bidding criteria considered by crane agents are a) container shipment demand, type, and destination; b) available hatch capacity; c) crane accessibility to hatches; and d) order of bay allocation to avoid bow–stern imbalances. The interactive structure of crane agents with IES is shown in Figure 2.

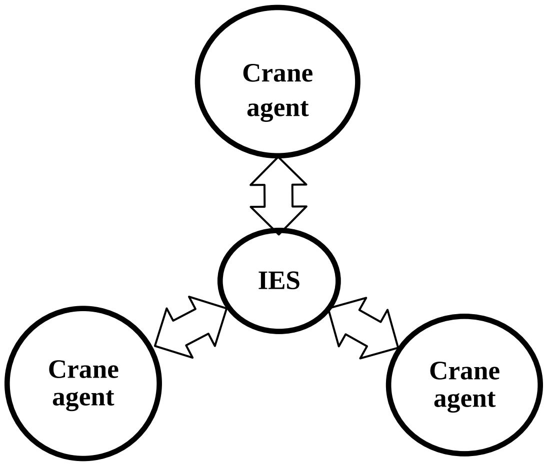

Figure 2: Interaction of crane agents with IES

4.1.2. Stage 2 – Block allocation

The shipment demand allotted in Stage 1 to hatches are divided based on its location into port side (PS) blocks, port side inter-hatch (PSIH) blocks, central blocks (CB), starboard side inter-hatch (SSIH) blocks, and starboard side (SS) blocks to allocate slots considering the horizontal stability of the ship. The IES interacts with ship captain and presents redemption value of bundled shipment demand to block agents considering the ship stability and structural restrictions. The block agents in turn submit bids, considering the ship horizontal stability, based on the redemption value provided by IES to match the container characteristics with ship structure. The experiments are run by IES based on the bid values and the blocks are allocated to the bundle of containers. This interactive structure of block agents with IES is shown in Figure 3.

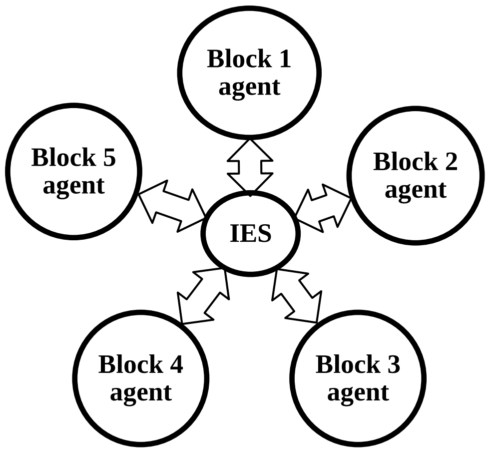

Figure 3: Interactive structure of block agents with IES

4.1.3. Stage 3 – Tier allocation

In this stage, the container location with tier conflicts, that is, placing containers in top or bottom slots, are identified from Stage 2 and are reallocated to provide vertical balancing and avoid rehandling. Here, the containers, based on destination and type, are represented as tier agents to interact with the ship captain to confine to the ship characteristics through IES. Experiments are then conducted by IES based on the redemption value set by the ship captain defining ship properties and the bid values submitted by the tier agents. The interactive structure of the tier agents with IES is shown in Figure 4.

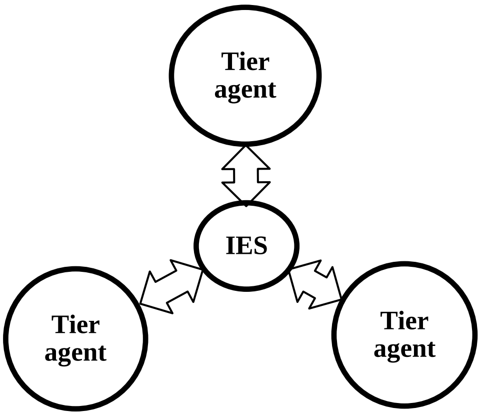

Figure 4: Interactive structure of Tier agents with IES

4.2. Experimental market design for bidding agents with IES

This section presents the design and implementation of market mechanism experimentally based on ICA. In ICA, the bid values are received from the agents and the evaluation is done based on the complete enumerative logical search algorithm discussed in Section 4.3.1 and Section 4.3.2. A formal market model with continuous clearing and competitive equilibrium pricing policies among zero-intelligence agents is considered, and the experiments are conducted to match the demand and supply of ship slots. Therefore, agents are allowed to generate random bids uniformly distributed over the range of values chosen from the redemption values. In the experiments, uniformly distributed random values are generated using Microsoft Excel function Randbetween (bottom, top) by the bidders (agents) and submitted to IES as a bid for a bundle of resources. The experimenter (IES) uses these randomly submitted bid values in each experiment and chooses a suitable output for an experiment.

4.3. Solution procedure for MAS with ICA in experimental markets

The steps followed to prepare a stowage plan using the MAS approach are:

Step 1: Input the ship route, container shipment demand among ports, container and ship characteristics, crane availability, crane location, crane accessibility to hatches, crane movement time between hatches, and crane loading time to slot locations.

Step 2: Allocation of hatch to cranes:

2.1. Sort the containers for shipment based on its destination and type.

2.2. Divide the shipment demand based on the hatch capacity as per the bundling assumptions, and outline the auction rounds for the allocation of hatches to crane agents.

2.3. Initiate the experiment (n_e) among the crane agents by providing the redemption value to the bidders for each step (st) in the auction round (ar).

2.4. Collect the bid that considers cross-equilibrium of the ship and minimum crane movement time from the crane agents.

2.5. Run the ICA mechanism and determine the winner of the hatch, VCG payment, universal competitive equilibrium price, and market revenue for the experimenter among N_e experiments. The profit earned by the crane agents is calculated from the suitable output among N_e experiments using the relation:

Profit earned by crane agent = redemption value for the corresponding hatch set by the ship captain – VCG payment made by the crane agent.

2.6. Repeat all steps (ST) and auction rounds (AR), and determine the total crane movement time and total profit earned by the crane agents.

Step 3: Allocation of containers to blocks in hatches:

3.1. The hatch allocations are divided into blocks—port side, port side inter-hatch, central blocks, starboard side inter-hatch, and starboard side blocks—and their capacity is noted.

3.2. The blocks are represented as agents and allowed to bid based on the redemption value set by the experimenter for bundled slots allotted to hatches.

3.3. Run an experiment (n_e) and ICA mechanism to determine the winner block agent, VCG payment, universal competitive equilibrium price, and market revenue for the experimenter among N_e experiments. The profit earned by the block agents is calculated from the suitable output among N_e experiments by using the relation:

Profit earned by crane agent = redemption value for the corresponding block set by the ship captain – VCG payment made by the block agent.

3.4. Repeat it to all hatches and determine the total profit earned by the block agents.

Step 4: Allocation of containers to tier in blocks for vertical equilibrium:

4.1. The containers with conflicts on vertical balancing are formed into top and bottom slots.

4.2. Conflict slots are bundled for top and bottom tier agents, and the redemption value is set by the experimenter to initiate the ICA mechanism.

4.3. Bids are collected from top and bottom agents to obtain the vertical equilibrium for each block.

4.4. Run an experiment (n_e) and an ICA mechanism to determine the winner of the blocks, VCG payment, universal competitive equilibrium price, and market revenue for the experimenter among N_e experiments. The profit earned by the tier agents is calculated from the suitable output among N_e experiments using the relation:

Profit earned by tier agent = redemption value for the corresponding tier set by the ship captain – VCG payment made by the tier agent.

4.5. Repeat it to all blocks that have conflict in tier allocation and vertical equilibrium.

4.6. Calculate the total profit for the top and bottom agents.

Step 5: The bay plan is prepared from the allocations, and the slot loading time for each bay is determined.

Step 6: The total loading time for the ship at the origin port and the total profit for agents involved in stowage planning are calculated, and the order of allocating the hatches is presented.

The flowchart for solving the MBPP and preparing a bay plan with minimum loading time is shown in Figure 5.

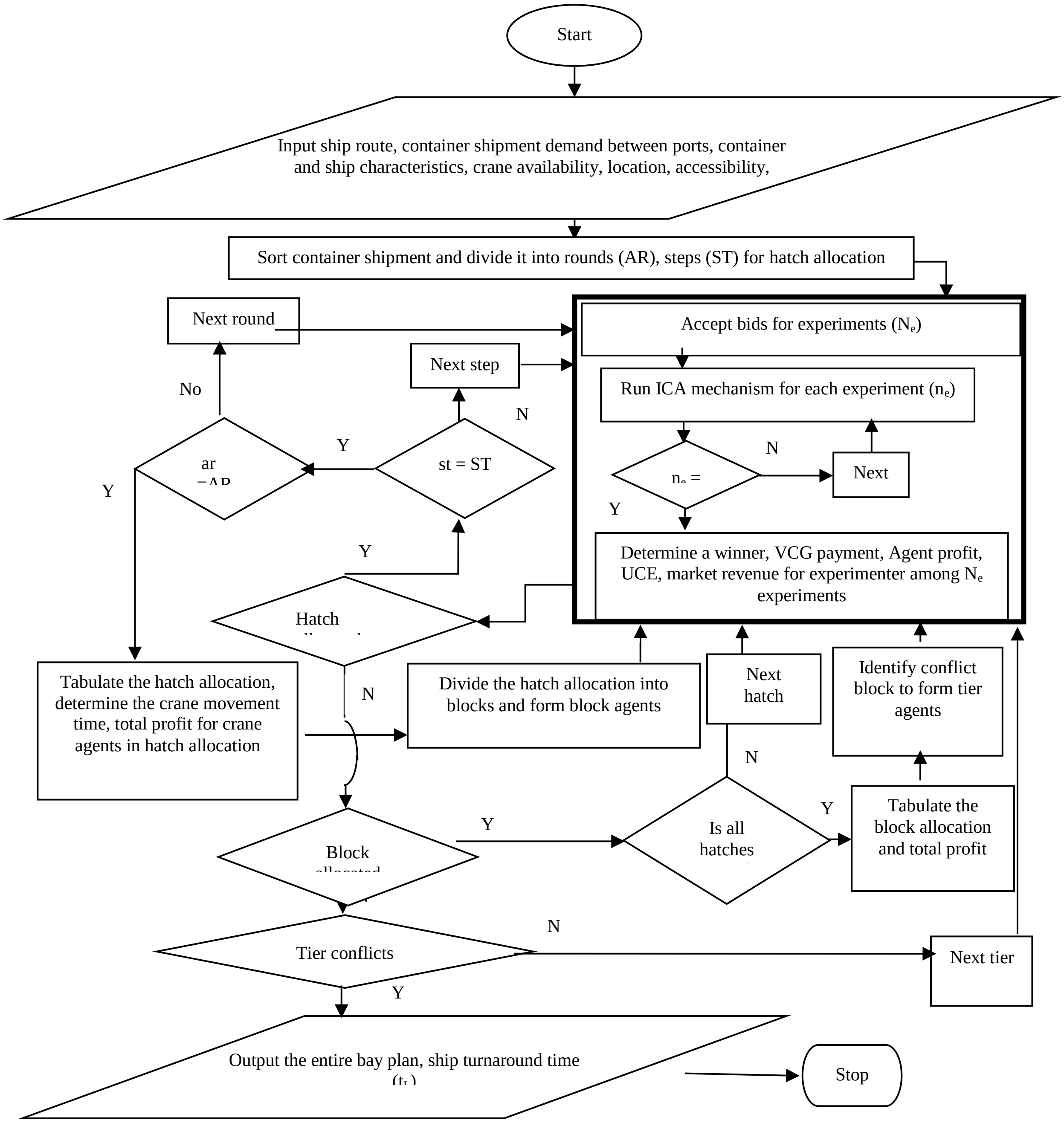

Figure 5: Solution procedure for MBPP

The solution procedure of the software program developed for ICA to implement the MAS is explained as follows.

4.3.1. Complete enumerative logical search algorithm

IES uses the complete enumerative logical search algorithm to determine the VCG payment, agent profit, competitive equilibrium price, and slot allocation in ICA mechanism. The steps are:

Step 1: The agents (N_B) are allowed to bid ($BV_{(NB,BS)}$) bundled sets of the IES.

Step 2: Iteration count in the auction is set from 0 to large value.

Step 3: If iteration value is zero, set the auction value of all buyers and bundle sets ($AV_{(NB,BS)}$) as zero, run winner determination algorithm, including all buyers using its bid value in Step 1, and determine an initial allocation ($AL_{(NB,BS)}$).

Step 4: Update the array of agents (bidders) with one if allocated and zero if the agents are not allocated.

Step 5: The auction values are incremented for each agent without allocation in the previous iteration if:

Step 5.1: The bid value is not equal to zero, and

Step 5.2: The bundle set that has maximum bid value for each agent, and

Step 5.3: The auction value of the bundle set with a maximum bid value is equal to the bid value of any other bundled set of the same agent, and

Step 5.4: The auction value is less than the bid value for the corresponding bid set.

Step 6: Run winner determination algorithm with all agents, and by excluding one agent for (N_B + 1) times, calculate the revenue of IES in (N_B + 1) markets by adding the auction values for the allocated bundle sets and go to Step 4, else:

Step 7: If auction value is equal to bid value for any agent and for any bundle sets, run the winner determination algorithm with all agents and exclude one agent for (N_B + 1) times, and calculate the revenue of IES (N_B + 1) markets by adding the auction values for the allocated bundle sets.

Step 8: Store the allocation as final allocation ($AL_{(NB,BS)}$) of bundle sets to the agents.

Step 9: Calculate the maximum auction value (competitive equilibrium price) considering all agents in the market, and store the bundle set and agent containing the maximum auction value.

Step 10: Increment the auction value if:

Step 10.1: The agent to be incremented is not the agent containing the maximum auction value.

Step 10.2: The maximum bid value of the agent for the bundle sets is greater than the maximum auction value from Step 9.

Step 10.3: Run winner determination algorithm with all agents and by excluding one agent for (N_B + 1) times.

Step 11: Calculate the IES revenue for the final allocation as in Step 8 using the auction value in Step 10 for (N_B + 1) markets.

Step 12: Else, if:

Step 12.1: The agent is not the agent with the maximum auction value found in Step 9, and

Step 12.2: The auction value of any other agent is equal to the maximum auction value as in Step 9.

Step 13: Run winner determination algorithm with all agents and exclude one agent for (N_B + 1) times.

Step 14: Calculate the IES revenue for the final allocation in Step 8 using the auction value in Step 12 for (N_B + 1) market at the Universal Competitive Equilibrium (UCE) price, stop iteration.

Step 15: Calculate agent's VCG payment using the equation:

Buyer's VCG Payment = {(Sum of auction value of allocated set of slots to the agent) – [(IES revenue in market of all agents (SR_{NB})) – (IES revenue in market without the agent to whom the payment is calculated (SR_{NB-nb}))]}

Step16: Output the final allocation in all markets, VCG payments of all agents.

The function used in the software program to determine the winner in each auction round is presented in the next section.

4.3.2 Winner determination algorithm

The algorithm to determine the winner of the bundles in each increment of an ICA experiment is given below.

Step 1: Input number of bundles (m), number of agents (N_B).

Step 2: Calculate the BS = 2^m number of combinations, with each combination that contains the set of bundles.

Step 3: Obtain auction value for all the bundles set from the ICA loop for each winner determination algorithm execution.

Step 4: Calculate the summation of auction value for $2^{(BS)*(NB)}$ allocations checking for the non-repetition of bundles and sets.

Step 5: Count the number of winners in each allocation.

Step 6: Choose the allocation with maximum auction value summations and the number of winners.

The output of the complete enumerative search algorithm is used by the experimenter in evaluating the experimental market design for solving the MBPP and loading time for the ship at the origin port. The total profit for agents involved in stowage planning is calculated, and the order of allocating the hatches is also determined. The above solution procedure is illustrated using the data from the benchmark problem in the section 5.

5. Numerical evaluation

This section presents the numerical evaluation of the market with a MAS model and an ICA mechanism to prepare the stowage plan. The ship is considered with port rotation as shown in Figure 6 and container loading at origin port (Busan) considering the stowage constraints discussed in the section.

5.1. Input details for illustrative work

The details of container characteristics, ship characteristics, and loading time for crane to slots in each hatch obtained from the bench mark problem (Wilson and Roach, 1999) are presented below.

Figure 6: The cyclic ship route considered for illustration

5.1.1. Container characteristics

The shipment demand of two different types of containers to ports along the ship itinerary is given in Table 1. In the illustration, the stowage of nonstandard dimensions containers, hazardous containers, and reefer containers are not considered to concisely explain the adapted solution methodology.

Table 1: Container characteristics

Destination port	Port number	Type in foot length	Total demand in TEU
Osaka	1	20	217
		40	48
Keelung	2	20	185
		40	34
Kaohsung	3	20	94
		40	110
Total			**688**

5.1.2 Ship characteristics

The nine-hatch, 688 TEU capacity container ship is used to test the methodology. The ship's structural restrictions to stow containers are: a) all above-deck bays can have any length of container stowed; b) under-deck hatches 1 and 8 can have 40-foot and 20-foot containers stowed; c) under-deck hatches 2 and 7 can only have 20-foot containers stowed; and d) under-deck hatches 3, 4, 5, and 6 can only have 40-foot containers stowed. The details presenting the number of bays, rows, and tiers available for stowage planning in the ship is given in Table 2.

Table 2: Ship structural details

Number of hatches	Number of bays	Number of rows	Number of tiers		Total capacity (TEU)
			Below deck	Above deck	
9	35	6 to 8	2 to 6	2 or 3	688

5.1.3 Crane accessibility and loading time to ship slots

Based on the ship structure, quay cranes will be operated and positioned with successive cranes placed after two bay lengths. Therefore, it is assumed three quay cranes are used and positioned near hatches 1, 4, and 7. The possibility of crane arrangement without collision among crane operations is shown in Table 3.

Table 3: Crane accessibility

Crane number	**1**	**2**	**3**
Accessibility	Hatch 1, 2, 3	Hatch 4, 5, 6	Hatch 7, 8, 9

As each crane hook acquires time to be transferred to its accessible bays, the time to position it for loading is assumed and presented in Table 4. It assists the crane agents in bidding suitably and minimizing the crane movement time to hatches.

Table 4: Crane positioning time to hatches

Crane location	**Crane number**	**Hatch number**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
At hatch 1	1	0’	45’’	65”	-	-	-	-	-	-
At hatch 4	2	-	-	-	0’	45’’	65”	-	-	-
At hatch 7	3	-	-	-	-	-	-	0’	45’’	65”

The loading times with respect to each tier and row of the containership are also assumed and presented in Table 5.

Table 5: Loading time for crane to slots in each hatch in hours: minutes: seconds

	Row 08	**Row 06**	**Row 04**	**Row 02**	**Row 01**	**Row 03**	**Row 05**	**Row 07**
Tier 86	0:00:34	0:00:32	0:00:31	0:00:29	0:00:28	0:00:29	0:00:31	0:00:32
Tier 84	0:00:35	0:00:34	0:00:32	0:00:31	0:00:29	0:00:31	0:00:32	0:00:34
Tier 82	0:00:38	0:00:36	0:00:35	0:00:33	0:00:32	0:00:33	0:00:35	0:00:36
Tier 12	0:00:37	0:00:35	0:00:34	0:00:32	0:00:31	0:00:32	0:00:34	0:00:35
Tier 10	0:00:38	0:00:37	0:00:35	0:00:34	0:00:32	0:00:34	0:00:35	0:00:37
Tier 08	0:00:40	0:00:38	0:00:37	0:00:35	0:00:34	0:00:35	0:00:37	0:00:38
Tier 06	0:00:42	0:00:40	0:00:38	0:00:37	0:00:35	0:00:37	0:00:38	0:00:40
Tier 04	0:00:43	0:00:42	0:00:40	0:00:38	0:00:37	0:00:38	0:00:40	0:00:42
Tier 02	0:00:44	0:00:43	0:00:41	0:00:39	0:00:38	0:00:39	0:00:41	0:00:43

5.2. Stowage steps to allocate slots

The details presented in Section 5.1 are used as follows to solve MBPP using MAS methodology.

5.2.1. Stage 1 – Hatch allocation to cranes

Based on the container type and destination, the number of rounds to allocate the containers to ship slot is determined. For each container type in a destination, an allocation round is formed. Then the container shipment to each destination is split into steps based on the capacity in each bay. The details of allocation are provided in Table 6.

Table 6: Allocation round, steps based on bay capacity, slot demand, and container characteristics

Round No(AR)	Number of steps(ST)	Allocation (TEU)					Total demand (TEU)	Destination	Container type (20' or 40')
		Step 1	Step 2	Step 3	Step 4	Step 5			
1	5	48	48	48	48	25	217	1	20
2	1	48	-	-	-	-	48		40
3	4	48	48	48	41	-	185	2	20
4	1	34	-	-	-	-	34		40
5	2	48	46	-	-	-	94	3	20
6	3	48	48	14	-	-	110		40

In each step, a set of "N_e" experiments are run by the experimenter in IES and the desired hatch allocation to the crane is made by the experimenter. The redemption value provided by the experimenter for each bundle of shipment demands and the randomly generated bid value for the crane agents for the desired output for all steps and rounds to initiate the ICA mechanism are presented in Appendix 2.

The hatch allocation, choice of the hatch, CE price, VCG payment to the crane agents, revenue to the experimenter in conducting the experiment, and profit of each crane agent are calculated and presented in Table 7.

Table 7: Hatch allocation with VCG payment and profit earned by crane agents in auction steps

Round	Iteration	Revenue & CE	Revenue/ UCE	Crane allocation	Order of hatch allocation	Agent VCG (Rs)	Agent profit (Rs)	Bundle sets		Bundle allocation (TEU) {0}	{1}	{2}	{3}	{12}	{13}	{23}	{123}
1	1	2,2,0,2, CE = 2	(3,3,1,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				48	5	2	11		2	-	16	-	-	-	-	32	-
						0	0		3	-	-	-	-	-	-	-	-
	2	2,2,0,2 CE = 2	(3,3,1,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				48	6	2	14		2	-	16	-	-	-	-	32	-
						0	0		3	-	-	-	-	-	-	-	-
	3	2,2,2,2 CE = 2	(3,3,3,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				32	4	0	14		2	-	-	-	-	-	-	32	-
				16	7	0	4		3	-	16	-	-	-	-	-	-
	4	8,8,7,8 CE = 8	(8,8,7,8)/8					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				16	4	1	3		2	-	16	-	-	-	-	-	-
				32	7	0	16		3	-	-	-	-	-	-	32	-
	5	2,2,2,1 CE = 2	(3,3,3,2)/3					Bundle size (TEU)		0	5	5	15	10	20	20	25
						0	0	Crane agent no.	1	-	-	-	-	-	-	-	-
						0	0		2	-	-	-	-	-	-	-	-
				25	8	1	15		3	-	5	-	-	-	-	20	-
2 UD	1	2,2,0,2 CE = 2	(3,3,1,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				48	5	2			2	-	16	-	-	-	-	32	-

						0			3	-	-	-	-	-	-	-	-
3	1	2,1,2,2 CE = 2	(3,2,3,3/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
				48	3	1	19	Crane agent	1	-	16	16	16	-	-	-	-
						0	0		2	-	-	-	-	-	-	-	-
						0	0		3	-	-	-	-	-	-	-	-
	2	3,3,3,1 CE = 3	(3,3,3,1/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
						0	0		2	-	-	-	-	-	-	-	-
				48	7 UD	2	6		3	-	16	16	16	-	-	-	-
	3	2,2,2,2 CE = 2	(3,3,3,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
				32	2	0	9	Crane agent	1	-	-	-	-	-	-	32	-
						0	0		2	-	-	-	-	-	-	-	-
				16	8	0	1		3	-	16	-	-	-	-	-	-
	4	4,4,4,3 CE = 4	(4,4,4,3)/4					Bundle size (TEU)		0	11	15	15	26	26	30	41
				26	2 UD	0	15	Crane agent	1	-	11	-	15	-	-	-	-
						0	0		2	-	-	-	-	-	-	-	-
				15	8 UD	1	3		3	-	-	15	-	-	-	-	-
4	1	3,3,2,3 CE = 3	(3,3,3,3)/3					Bundle size (TEU)		0	12	12	10	24	22	22	34
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				34	6	0	4		2	-	12	12	10	-	-	-	-
						0	0		3	-	-	-	-	-	-	-	-
5	1	2,2,2,2 CE = 2	(3,3,3,3)/3					Bundle size (TEU)		0	24	12	12	36	36	24	48
				24	1	0	11	Crane agent	1	-	-	-	-	-	-	24	-
						0	0		2	-	-	-	-	-	-	-	-
				24	9	0	2		3	-	24	-	-	-	-	-	-
	2	7,7,7,6 CE = 7	(9,9,9,8)/9					Bundle size (TEU)		0	16	16	14	32	30	30	46
				30	1,2 (24 and 6)	0	28	Crane agent no.	1	-	-	-	-	-	-	30	-
						0	0		2	-	-	-	-	-	-	-	-
				16	8 (7AD, 9 UD)	1	6		3	-	16	-	-	-	-	-	-
6	1	2,2,2,2 CE = 2	(2,2,2,2)/2					Bundle size (TEU)		0	4	5	5	9	9	10	14
						0	0	Crane Agent	1	-	-	-	-	-	-	-	-
				14	6	0	9		2	-	-	-	-	-	-	-	14
						0	0		3	-	-	-	-	-	-	-	-
	2	2,2,1,2 CE = 2	(3,3,2,3)/3					Bundle size (TEU)		0	16	16	16	32	32	32	48
						0	0	Crane agent	1	-	-	-	-	-	-	-	-
				48	4	1	10		2	-	16	-	-	-	-	32	-
						0			3	-	-	-	-	-	-	-	-
	3	2,2,2,2 CE = 2	(2,2,2,2)/2					Bundle size (TEU)		0	16	16	16	32	32	32	48
				48	3	0	10	Crane agent	1	-	-	-	-	-	-	-	48
						0	0		2	-	-	-	-	-	-	-	-
						0	0		3	-	-	-	-	-	-	-	-

The allocation to the agents is done at CE price, and the VCG payments and revenue of the experiment are calculated at the universal competitive equilibrium (UCE) price that does not change due to changes in the market economy. Thus the general arrangement of containers in hatches is obtained. Based on the hatch allocation to the cranes, the crane handling time is calculated. The order of hatch allocation is prepared based on container destination, priority in loading, and deck allocation. The container destination is represented by port number (1, 2, 3); the priority is represented by numbers from 1 to 6, i.e., above and below the deck allocation by number 1 and 2 respectively. Thus, the order of allocation

(111) represents the container with destination port 1, priority of hatch allocation 1, and deck allocation 1. The crane allocation and its transfer time between hatches are obtained and presented in Table 8.

Table 8: Crane movement time for hatch allocation

Allocation (TEU)	Hatch no.	Destination	Container type	Deck allocation	Order of allocation	Crane number	Crane movement (Crane number, from - to hatches)	Move time (sec)
48	5	1	40	UD	111	2	2,4-5	45
48	5	1	20	AD	112	2	-	-
48	6	1	20	AD	122	2	2,5-6	20
32	4	1	20	AD	132	2	2,6-4	65
16	4	1	20	AD	132	2	-	-
16	7	1	20	AD	142	3	3,7-7	0
32	7	1	20	AD	142	3	-	-
25	8	1	20	AD	152	3	3,7-8	45
34	6	2	40	UD	211	2	2,4-6	65
48	7	2	20	UD	221	3	3,8-7	45
16	8	2	20	UD	231	3	3,7-8	45
15	8	2	20	UD	231	3	-	-
26	2	2	20	UD	241	1	1,1-2	45
32	2	2	20	AD	242	1	-	-
48	3	2	20	AD	242	1	1,2-3	20
48	3	3	40	UD	311	1	-	-
16	8	3	20	AD and UD	321	3	3,8-8	0
24	1	3	20	AD	332	1	1,3-1	65
24	9	3	20	AD	342	3	3,8-9	20
14	6	3	40	UD	351	2	2,6-6	0
24	1	3	20	UD	361	1	1,1-1	0
6	2	3	20	UD	361	1	1,1-1	0
48	4	3	40	UD	361	2	2,6-4	65
						Total crane movement time (hours:minutes:seconds)		**0:09:05**

The overall profit for each crane agents after Stage 1 – hatch allocation is determined and presented in Table 9. To further control the lateral stability and operational constraints, the hatches are divided into blocks as illustrated in section 5.2.2 and allocated.

Table 9: Total profit earned by the crane agents

Crane agent	Agent 1	Agent 2	Agent 3
Profit (Rs)	92	65	53

5.2.2 Stage 2 – Block allocation to hatches

In this stage, the possible ways to divide the allocated slots into blocks in terms of its size and capacity (TEU – twenty-foot equivalent unit) is analyzed as per the constraints discussed in Section 4.3 and presented in Table 10 for each hatch and its corresponding bays.

Table 10: Block categorization based on bay capacity in hatches

Hatch no.	**Hatch capacity (TEU)**	**Block position (above deck/ below deck)**	**Bay type considered (odd/even)**	**Bay number**	**Slot size in feet**	**Number of blocks for a bay**	**Block category**	**Block size**	**Total TEU for a bay**
1	48	AD	Odd bay	01,03	20’	2	PS	6	6
							SS	6	6
			Even bay	2	40’	2	PS	6	12
							SS	6	12
		UD	Odd bay	01,03	20’	2	PS	6	6
							SS	6	6
			Even bay	2	40’	2	PS	6	12
							SS	6	12
2	64	AD	Odd bay	05,07	20’	2	PS	8	8
							SS	8	8
			Even bay	6	40’	2	PS	8	16
							SS	8	16
		UD	Odd bay	05,07	20’	2	PS	8	8
							SS	8	8
3 to 6	384	AD	Odd bay	9,11,13,15,17,19,21,23	20’	5	PS	6	6
							CB	6	6
							SS	6	6
							PSIH	3	3
							SSIH	3	3
			Even Bay	10,14,18,22	40’	5	PS	6	12
							CB	6	12
							SS	6	12
							PSIH	3	6
							SSIH	3	6
		UD	Even bay	10,14,18,22	40’	3	PS	5	10
							CB	14	28
							SS	5	10
7	96	AD	Odd bay	25,27	20’	5	PS	6	6
							CB	6	6
							SS	6	6
							PSIH	3	3
							SSIH	3	3
			Even bay	26	40’	5	PS	6	12
							CB	6	12
							SS	6	12
							PSIH	3	6
							SSIH	3	6
		UD	Odd bay	25,27	20’	3	PS	5	5
							CB	14	14
							SS	5	5
8	72	AD	Odd bay	29,31	20’	2	PS	8	8
							SS	8	8
			Even bay	30	40’	2	PS	8	16
							SS	8	16
		UD	Odd bay	29,31	20’	2	PS	10	10
							SS	10	10
			Even bay	30	40’	2	PS	10	20
							SS	10	20
9	24	AD	Odd bay	33, 35	20’	2	PS	6	6
							SS	6	6
			Even bay	34	40’	2	PS	6	12
							SS	6	12

Similar to Stage 1, block agents are formed, redemption values are received by the experimenter (IES), bid values are randomly generated for each experiment, “Ne” experiments are run, and the desired output of an experimenter is selected. The redemption value set by theexperimenter and bid value of agents for block allocation is presented in Table 11.

Table 11: Redemption value set by experimenter and bid value of agents for block allocation

Hatch	Agent	Redemption value of experimenter (Rs)							Bid values from the agent in experiment (Rs)						
	Bundle sets	{1}	{2}	{3}	{12}	{13}	{23}	{123}	{1}	{2}	{3}	{12}	{13}	{23}	{123}
1	PS	6	6	-	8	-	-	-	3	6	-	9	-	-	-
	SS	9	12	-	15	-	-	-	9	9	-	9	-	-	-
1	PS	9	10	-	13	-	-	-	3	4	-	4	-	-	-
	SS	7	10	-	11	-	-	-	3	3	-	4	-	-	-
2	PS	10	11	-	13	-	-	-	5	4	-	5	-	-	-
	SS	5	6	-	11	-	-	-	4	4	-	5	-	-	-
2	PS	7	9	-	12	-	-	-	8	7	-	8	-	-	-
	SS	5	8	-	11	-	-	-	6	7	-	8	-	-	-
3	PS	5	9	10	15	18	18	19	3	4	4	6	6	6	7
	CB	7	8	12	15	15	16	19	4	3	3	6	6	6	7
	SS	8	9	9	11	14	16	18	4	4	3	6	6	6	7
	PSIH	6	7	-	10	-	-	-	2	3	-	3	-	-	-
	SSIH	5	5	-	9	-	-	-	2	2	-	3	-	-	-
3	PS	5	6	6	9	9	12	13	3	4	3	7	6	7	8
	PSIH	-	-	-	-	-	-	-	2	3	-	3	-	-	-
	CB	5	5	7	8	10	12	20	4	3	3	6	7	7	8
	SSIH	-	-	-	-	-	-	-	2	2	-	3	-	-	-
	SS	5	8	9	10	11	13	16	3	4	3	7	6	7	8
4	PS	5	11	12	14	16	20	20	4	5	4	8	9	9	11
	CB	10	11	13	15	16	17	18	5	4	4	9	9	8	11
	SS	9	10	11	13	14	16	16	4	5	4	8	9	8	11
	PSIH	6	6	-	10	-	-	-	2	4	-	6	-	-	-
	SSIH	5	6	-	7	-	-	-	6	6	-	6	-	-	-
4	PS	5	7	9	11	12	12	13	5	5	6	11	9	9	12
	CB	6	6	8	13	16	18	18	6	6	5	9	9	11	12
	SS	6	8	9	14	16	17	20	6	5	6	11	11	9	12
	PSIH	5	6	-	8	-	-	-	4	4	-	5	-	-	-
	SSIH	6	7	-	11	-	-	-	4	5	-	5	-	-	-
4	PS	7	8	12	12	12	17	18	5	6	6	10	11	11	12
	CB	15	16	17	18	19	19	20	6	5	6	10	11	11	12
	SSIH	10	10	-	-	-	-	-	7	8	-	9	-	-	-
	SS	5	10	14	15	17	18	19	5	6	5	11	11	11	12
5	PS	5	10	12	12	13	16	18	2	3	2	5	5	4	7
	CB	5	6	8	10	10	11	13	2	2	2	4	4	4	7
	SS	6	7	8	11	13	14	14	2	3	2	5	4	4	7

5	PS	11	12	12	18	19	20	20	7	7	7	11	13	13	16
	CB	7	8	11	12	13	13	20	7	8	7	11	13	11	16
	SS	9	11	11	11	14	14	16	8	7	8	11	11	13	16
	PSIH	9	10	-	15	-	-	-	9	8	-	9	-	-	-
	SSIH	10	10	-	16	-	-	-	7	8	-	9	-	-	-
6	PS	7	9	9	13	16	16	16	7	9	9	11	11	12	14
	CB	9	9	9	11	11	12	14	9	7	9	11	11	11	14
	SS	10	10	11	14	15	15	17	7	9	7	12	12	12	14
	PSIH	6	9	-	10	-	-	-	2	6	-	12	-	-	-
	SSIH	7	7	-	10	-	-	-	12	12	-	12	-	-	-
6	PS	5	5	6	7	10	14	14	3	4	4	7	7	8	10
	CB	5	10	10	13	14	18	19	4	3	4	7	7	7	10
	SS	5	10	10	11	12	13	18	3	4	3	8	8	8	10
7	PS	7	8	10	15	15	16	17	6	6	5	13	14	15	16
	CB	9	10	10	12	15	15	16	6	5	5	12	10	10	16
	SS	5	6	6	7	11	13	16	5	6	6	7	10	12	16
	PSIH	6	10	-	14	-	-	-	2	2	-	3	-	-	-
	SSIH	5	7	-	9	-	-	-	2	3	-	3	-	-	-
7	PS	5	5	9	10	11	12	17	3	5	5	7	9	9	10
	CB	9	11	11	12	14	17	17	5	5	3	9	9	7	10
	SS	8	9	11	13	14	16	20	3	3	5	7	7	7	10
	PSIH	10	10	-	13	-	-	-	5	6	-	6	-	-	-
	SSIH	6	7	-	10	-	-	-	5	5	-	6	-	-	-
7	PS	13	14	14	17	17	19	19	9	9	9	12	12	12	16
	CB	9	9	15	15	15	16	19	9	9	6	12	12	9	16
	SS	6	6	9	9	12	15	16	6	6	9	9	12	12	16
8	PS	5	5	-	8	-	-	-	1	2	-	3	-	-	-
	SS	6	8	-	9	-	-	-	3	3	-	3	-	-	-
8	PS	5	7	-	9	-	-	-	3	2	-	3	-	-	-
	SS	5	5	-	8	-	-	-	2	3	-	3	-	-	-
9	PS	6	6	-	10	-	-	-	6	6	-	6	-	-	-
	SS	6	9	-	10	-	-	-	6	3	-	9	-	-	-

Using the bid values for each block bundles, the experiment is run. VCG payment and profit for each block agent at UCE, revenue, and allocation to block agents at CE are determined and presented in Table 12.

Table 12: Allocation of blocks, VCG payment to experimenter, and profit after redemption in desired experiment

Hatch	Revenue in markets (All buyers, Excluding first, Second buyers and UCE) (Rs)	Revenue in markets (All buyers, Excluding first, Second buyers and CE) (Rs)	Agent	Bundle allocation (TEU)	VCG (Rs)	Profit(Rs) (Redemption value – VCG)
1	12,12,9 UCE = 12	6,6,6 CE = 6	**PS**	12	0	6
1	12,12,9 UCE = 12	6,6,6 CE = 6	**SS**	12	3	9
1	4,4,4 UCE = 4	4,4,4 CE = 4	**PS**	12	0	10
1	4,4,4 UCE = 4	4,4,4 CE = 4	**SS**	12	0	7
2	5,5,4 UCE = 5	5,5,4 CE = 5	**PS**	16	0	10
2	5,5,4 UCE = 5	5,5,4 CE = 5	**SS**	16	1	5
2	8,8,7 UCE = 8	8,8,7 CE = 8	**PS**	16	0	7
2	8,8,7 UCE = 8	8,8,7 CE = 8	**SS**	16	1	7
3	6,5,5,6 UCE = 5	5,5,5,5 CE = 5	**PS**	12	1	4
3	6,5,5,6 UCE = 5	5,5,5,5 CE = 5	**CB**	12	1	7
3	6,5,5,6 UCE = 5	5,5,5,5 CE = 5	**SS**	12	0	9
3	3,3,3 UCE =3	3,3,3 CE =3	**PSIH**	6	0	7
3	3,3,3 UCE =3	3,3,3 CE =3	**SSIH**	6	0	5
3	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**PS**	16	0	6
3	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**CB**	16	0	5
3	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**SS**	16	0	5
4	6,6,6,6 UCE = 6	6,6,6,6 CE = 6	**PS**	8	0	12
4	6,6,6,6 UCE = 6	6,6,6,6 CE = 6	**CB**	8	0	11
4	6,6,6,6 UCE = 6	6,6,6,6 CE = 6	**SS**	8	0	9
4	8,8,6 UCE =8	4,4,4 CE = 4	**PSIH**	4	0	6
4	8,8,6 UCE =8	4,4,4 CE = 4	**SSIH**	4	2	4
4	8,8,8,8 UCE = 8	8,8,8,8 CE = 8	**PS**	4	0	5
4	8,8,8,8 UCE = 8	8,8,8,8 CE = 8	**CB**	4	0	8
4	8,8,8,8 UCE = 8	8,8,8,8 CE = 8	**SS**	4	0	8
4	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**PSIH**	2	0	5
4	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**SSIH**	2	0	7
4	9,9,8,8 UCE = 5	9,9,8,8 CE = 5	**PS**	16	0	7
4	9,9,8,8 UCE = 5	9,9,8,8 CE = 5	**CB**	16	1	15
4	9,9,8,8 UCE = 5	9,9,8,8 CE = 5	**SSIH**	-	-	-
4	9,9,8,8 UCE = 5	9,9,8,8 CE = 5	**SS**	16	1	13
5	3,3,3,3 UCE = 3	3,3,3,3 CE = 3	**PS**	16	0	12
5	3,3,3,3 UCE = 3	3,3,3,3 CE = 3	**CB**	16	0	6
5	3,3,3,3 UCE = 3	3,3,3,3 CE = 3	**SS**	16	0	6
5	12,12,12,12 UCE = 12	12,12,12,12 CE = 12	**PS**	12	0	12
5	12,12,12,12 UCE = 12	12,12,12,12 CE = 12	**CB**	12	0	7
5	12,12,12,12 UCE = 12	12,12,12,12 CE = 12	**SS**	12	0	11
5	9,9,8	9,9,8	**PSIH**	6	0	9

	UCE = 9	CE = 9	**SSIH**	6	1	9
6	15,15,15,15 UCE = 15	15,15,15,15 CE = 15	**PS**	12	0	9
			CB	12	0	9
			SS	12	0	10
	4,4,4 UCE = 4	4,4,4 CE = 4	**PSIH**	6	0	6
			SSIH	6	0	7
6	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**PS**	10	0	5
			CB	28	0	10
			SS	10	0	10
7	9,9,8,8 UCE = 9	9,9,8,8 CE = 9	**PS**	4	0	10
			CB	4	1	9
			SS	4	1	4
	3,3,3 UCE = 3	3,3,3 CE = 3	**PSIH**	2	0	6
			SSIH	2	0	7
7	5,5,5,5 UCE = 5	5,5,5,5 CE = 5	**PS**	8	0	5
			CB	8	0	11
			SS	8	0	9
	6,6,6 UCE = 6	6,6,6 CE = 6	**PSIH**	4	0	10
			SSIH	4	0	6
7	15,15,15,15 UCE = 15	15,15,15,15 CE = 15	**PS**	16	0	14
			CB	16	0	15
			SS	16	0	6
8	2,2,2 UCE = 2	2,2,2 CE = 2	**PS**	16	0	5
			SS	16	0	8
8	2,1,1 UCE = 2	2,1,1 CE = 2	**PS**	20	1	4
			SS	20	1	4
9	6,6,6 UCE = 6	6,6,6 CE = 6	**PS**	12	0	6
			SS	12	0	9

The total profit of block agents from all experiments in Stage 2 is provided in Table 13, and the allocation to the blocks are presented in Table 14.

Table 13: Total profit earned by the block agent

Agent type	Port side agent (PS)	Port side inter-hatch agent (PSIH)	Central block agent (CB)	Starboard side inter-hatch agent (SSIH)	Starboard side agent (SS)

Profit (Rs)	159	49	113	45	159

Table 14: Allocation of containers to blocks

Allocation (TEU)	Hatch no.	Destination	Type	Deck allocation	Order of allocation	Crane no.	Bay number	Number of blocks	Block type				
									PS	PSIH	CB	SSIH	SS
24	1	3	20	AD	332	1	01,03	2	12				12
24	1	3	20	UD	361	1	01,03	2	12				12
26 & 6	2	2 & 3	20	UD	241	1	05,07	2	16				16
32	2	2	20	AD	242	1	05,07	2	16				16
48	3	2	20	AD	242	1	09,11	5	12	6	12	6	12
48	3	3	40	UD	311	1	10	3	16		16		16
32	4	1	20	AD	132	2	13,15	5	8	4	8	4	8
16	4	1	20	AD	132	2	13,15	5	4	2	4	2	4
48	4	3	40	UD	361	2	14	3	16		16		16
48	5	1	40	UD	111	2	18	3	16		16		16
48	5	1	20	AD	112	2	17,19	5	12	6	12	6	12
48	6	1	20	AD	122	2	21,23	5	12	6	12	6	12
34 & 14	6	2 & 3	40	UD	211 & 351	2	22	3	10		28		10
16	7	1	20	AD	142	3	25,27	5	4	2	4	2	4
32	7	1	20	AD	142	3	25,27	5	8	4	8	4	8
48	7	2	20	UD	221	3	25,27	3	16		16		16
25 & 7	8	1 & 3	20	AD	152 & 321	3	29,31	2	16				16
31 & 9	8	2 & 3	20	UD	231 & 321	3	29,31	2	20				20
24	9	3	20	AD	342	3	33,35	2	12				12

From the output in Table 14, it is observed that there are conflicts in arranging the container in cells of the block to avoid rehandles. Hence, the conflicting hatches (2, 6, and 8) are identified, and Stage 3 is initiated to allocate containers in tiers.

5.2.3. Stage 3 - Tier allocation in blocks

Agents are informed by IES to demand containers in top or bottom tiers satisfy the structural and operational constraints. The redemption values are set by the experimenter, the bid values are submitted by agents for each experiment, and the desired output is selected after “Ne” experiments. The redemption and bid value for the tier allocation is shown in Table 15.

Table 15: Redemption value set by experimenter and bid value of agents for Tier allocation

Block location	Hatch	Bay number	Destination	Tier agents	Bundle formation	Redemption value	Bid value

					{1}	{2}	{12}	{1}	{2}	{12}	{1}	{2}	{12}
PS	2	7	2	Top	5	3	8	4	4	6	2	2	2
			3	Bottom	5	3	8	3	6	7	2	3	3
SS	2	7	2	Top	5	3	8	3	7	8	3	3	4
			3	Bottom	5	3	8	5	5	10	3	4	4
CB	6	22	2	Top	14	14	28	3	4	8	4	4	4
			3	Bottom	14	14	28	5	5	8	3	4	4
PS	8	29 UD	2	Top	9	1	10	5	6	9	4	5	5
			3	Bottom	9	1	10	5	6	10	5	4	5
SS	8	29 UD	2	Top	9	1	10	6	7	9	7	7	8
			3	Bottom	9	1	10	6	8	8	7	8	8
PS	8	31 UD	2	Top	6	4	10	7	8	9	2	1	2
			3	Bottom	6	4	10	4	5	9	1	1	2
SS	8	31 UD	2	Top	7	3	10	2	3	5	5	5	5
			3	Bottom	7	3	10	7	9	10	4	5	5

The tier allocation at CE, VCG payment, and tier agent profit at UCE of the desired output in an experiment are presented in Table 16.

Table 16: Tier allocation, VCG payment, and profit after redemption in desired experiment

Block allocation	Hatch	Bay number	Destination	Tier agents	Bundle allocation			UCE (Rs)	CE (Rs)	VCG (Rs)	Profit (Rs)
					{1}	{2}	{12}				
PS	2	7	2	Top	5	-	-	2,1,2	2,1,2	1	3
			3	Bottom	-	3	-	UCE = 2	CE = 2	0	6
SS	2	7	2	Top	5	-	-	4,4,4	4,4,4	0	3
			3	Bottom	-	3	-	UCE = 4	CE = 4	0	5
CB	6	22	2	Top	14	-	-	2,1,2	2,1,2	1	2
			3	Bottom	-	14	-	UCE = 2	CE = 2	0	5
PS	8	29 UD	2	Top	9	-	-	2,1,1	2,1,1	1	4
			3	Bottom	-	1	-	UCE = 2	CE = 2	1	5
SS	8	29 UD	2	Top	9	-	-	8,8,8	8,8,8	0	6
			3	Bottom	-	1	-	UCE = 8	CE = 8	0	8
PS	8	31 UD	2	Top	6	-	-	2,2,1	2,2,1	0	7
			3	Bottom	-	4	-	UCE = 2	CE = 2	1	4
SS	8	31 UD	2	Top	7	-	-	2,1,2	2,1,2	1	1
			3	Bottom	-	3	-	UCE = 2	CE = 2	0	8

The total profit earned in Stage 3 by the tier agents after redeeming its allocation to the experimenter are calculated and presented in Table 17.

Table 17: Overall profits of tier agents

Agent type	Top tier agent	Bottom tier agent
Profit (Rs)	26	41

6. Results and comparison

The results obtained from the MAS methodology with an ICA mechanism for MBPP are discussed in this section. The sample bay plan obtained for a particular hatch designated by bay number, row number, and tier number to identify the location of the container with port of origin and destination in a ship is presented in Figure 7.

Hatch No.2

Bay No.5

Row → / Tire ↓	08	06	04	02	01	03	05	07
84	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210
82	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210

Hatch Plate

	04	02	01	03
10	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210
08	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210
06	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210
04		**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	
02		**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	

Bay No.7

Row / Tire	08	06	04	02	01	03	05	07
84	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210
82	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210	Busan/Keel 12T 2210

Hatch plate

	04	02	01	03
10	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210
08	**Busan/Keel 12T 2210**	**Busan/Keel 12T 2210**	Busan/Keel 12T 2210	Busan/Keel 12T 2210
06	**Busan/Keel 12T 2210**	**Busan/Kaoh 12T 2210**	Busan/Kaoh 12T 2210	Busan/Keel 12T 2210
04		**Busan/Kaoh 12T 2210**	Busan/Kaoh 12T 2210	
02		**Busan/Kaoh 12T 2210**	Busan/Kaoh 12T 2210	

Figure 7: Sample bay plan obtained using MAS approach for hatch 2

The sample bay plan shows the arrangement of containers at port Busan after resolving the rehandling conflicts of the containers to the ports of destination Kaoh and Keel. The 2210 marked on the containers represents that two 20-foot end- and side-opening containers with passive vents on top of external height

8 feet 6 inches can be placed, while 4210 represent a single 40-foot container of the same type. 12T and 20T marked on the container in a bay plan represent the weight in tonnage of each container loaded on the ship. The total loading time, crane movement time, crane loading time, and order in allocating the hatches for ship stability are presented in Table 18.

Table 18: Ship turnaround time calculation

Hatch no.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Order of loading hatches	8	6	7	3	1	2	4	5	9
Loading time in hours:minutes:seconds	0:27:46	0:35:58	0:54:02	0:54:02	0:54:02	0:54:02	0:54:02	0:42:58	0:13:06
Crane loading time in hours:minutes:seconds	1:57:46			2:42:06			1:50:06		
Crane movement time in hours:minutes:seconds	0:02:10			0:04:20			0:02:35		
Total loading time in hours:minutes:seconds	1:59:56			2:46:26			1:52:41		
Ship turnaround time (t_L) considering only the loading time	**6 hours 39 minutes 03 seconds**								

Thus, the MBPP is solved using the MAS methodology by sharing the information through IES in terms of bid price regarding the container loading and stability constraints. The container loading time for a 688 TEU container ship is obtained and found comparable to the benchmark problem. Also, the entire bay plan of containership (688 TEU) is prepared and found similar to the bay plan of the benchmark problem. Moreover, the computation time for an auction experiment in MAS methodology is observed to be less than a fraction of a second with an Intel core i5 processor with 3.06 GHz, compared to 90 minutes taken by the heuristic approach of the benchmark problem to solve the MBPP. Further, the MAS methodology promoted sustainability by communicating true information among stowage planners. Even though the solutions are sustainable, the results depend on the bidder's ability to value the bundles in experiments. Moreover, the developed complete enumerative logical search algorithm suffers from computational and algorithmic complexity. The maximum computational complexity is N_B * (BS-1) * m, if all the bidders bid for all bundled bid sets (BS = 2^m) formed from m identical goods. The conclusion with the future research scope of MAS methodology is presented in next section.

7. Conclusion and future work

The arrangement of containers in the logistics chain is critical to provide the speedy delivery of resources from the area of supply to demand. In container logistics, it is necessary to gather the information on constraints in both ship and terminal to minimize the handling time of the containers. As the constraints on ship are critical in determining the efficiency of the container ship's trade, the MBPP needs a well designed, automated, effective heuristic methodology to be solved. Our paper contributes by designing a MAS with an ICA mechanism to provide information exchange on the constraints of the MBPP. Further, in ICA, to promote active participation of agents and truth revelation in IES, efficient CE allocation, and incentive-compatible payment rules like VCG are used. To evaluate the designed MAS methodology, market experiments with continuous clearing and CE pricing policy are conducted by IES to allow agents to communicate by bidding. Software developed to determine the allocation and payment in ICA are used by IES for successful implementation of MAS. Allocations at CE price in ICA are obtained, and the VCG payments for agents winning the allocation at UCE price are determined for the experiment. Similar experiments are conducted to allocate all the bundled slots to the ship, and the experimental results are consolidated to prepare the master bay plan. The quality of the solution (bay plan of the entire ship) is verified and found acceptable for the benchmark problem. Thus the information regarding the constraints in MBPP is effectively handled to obtain sustainable solutions using MAS methodology. The paper initiates the application of MAS methodology to solve MBPP, and provides scope for future studies on its limitations. It includes:

- Development of bundling procedure to combine a variety of heterogeneous non-identical goods for ICA.
- Need of agent to learn algorithm to assist the bidders to value the bundled sets in ICA.
- Development in complete enumerative logical search algorithm to validate ICA with more than three bidders and bundles.

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Appendix 1. Example to calculate the VCG payment in combinatorial auction.

Suppose there are three bidders {1, 2, 3} and two goods {1, 2}. The possible combination of goods to form bundles are {∅}, {1}, {2}, {1, 2}. The valuation profile by bidders are assumed and presented in Table A.1.

Table A1.1: Bidders' valuation of bundled goods

Bundle sets	Bid values (Rs)		
	Bidder 1	Bidder 2	Bidder 3
∅	0	0	0
{1}	2	0	0
{2}	0	4	2
{12}	2	4	4

The VCG payments at UCE in ICA based on the bidders' valuation profile is calculated using the relation:

VCG payment by bidder 1 = {Bid value of allocated bundle to bidder 1} – {Difference between the experimenter revenue in markets with all bidders and by excluding bidder 1}.

Similarly, the VCG payments for all the bidders are obtained. The calculations for markets with all bidders and the externality of bidders are presented in Table A.2.

Table A1.2: VCG payment for bidders

<table>
<tr><th rowspan="2">Market participants</th><th colspan="2">Allocation obtained from winner determination algorithm</th><th>Bid values for allocated bundles in ICA</th><th rowspan="2">Experimenter (IES) revenue (Rs)</th><th rowspan="2" colspan="2">VCG payment (Rs)</th></tr>
<tr><th>Bidder</th><th>Bundle set</th><th>Bid value</th></tr>
<tr><td rowspan="2">Bidders 1, 2 and 3</td><td>1</td><td>{1}</td><td>2 (X)</td><td rowspan="2">2 + 4 = 6 (A)</td><td rowspan="2" colspan="2">Not applicable</td></tr>
<tr><td>2</td><td>{2}</td><td>4 (Y)</td></tr>
<tr><td>Bidder 2 and 3</td><td>3</td><td>{1,2}</td><td>4</td><td>4 (B)</td><td>Bidder 1</td><td>X – (A – B) =2–(6-4) = 0</td></tr>
<tr><td rowspan="2">Bidder 1 and 3</td><td>1</td><td>{1}</td><td>2</td><td rowspan="2">2 + 2 = 4(C)</td><td rowspan="2">Bidder 2</td><td rowspan="2">Y – (A - C) = 4-(6-4) = 2</td></tr>
<tr><td>3</td><td>{2}</td><td>2</td></tr>
<tr><td rowspan="2">Bidder 1 and 2</td><td>1</td><td>{1}</td><td>2</td><td rowspan="2">2 + 4 = 6 (D)</td><td rowspan="2">Bidder 3</td><td rowspan="2">0 – (A-D) =0-(6-6) =0</td></tr>
<tr><td>2</td><td>{2}</td><td>4</td></tr>
</table>

Appendix 2. Redemption values and bid values for an experiment

Table A2.1: Redemption value of experimenter and bid value by crane agents for hatch allocation

Round	Step	Redemption value of experimenter (Rs)									Bid values from the agent in experiment (Rs)							
		Bundle sets	**{0}**	**{1}**	**{2}**	**{3}**	**{12}**	**{13}**	**{23}**	**{123}**	**{0}**	**{1}**	**{2}**	**{3}**	**{12}**	**{13}**	**{23}**	**{123}**
1	1	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	3	5	5	7	10	11	13	0	3	5	5	5	6	7	11
		2	0	1	1	3	3	10	12	12	0	1	1	3	3	5	9	9
		3	0	3	3	3	4	9	18	19	0	1	1	1	4	7	16	18
	2	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	2	6	13	20	20	23	24	0	1	1	5	15	15	21	23
		2	0	1	2	8	10	11	15	15	0	1	1	1	5	7	15	15
		3	0	5	6	7	7	12	12	14	0	3	5	6	6	9	9	13
	3	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	3	10	10	12	13	14	15	0	3	5	5	9	11	13	15
		2	0	3	7	8	8	12	14	14	0	2	2	3	5	6	12	12
		3	0	4	10	10	11	13	13	15	0	1	5	5	7	11	11	15
	4	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	7	9	11	12	13	13	13	0	4	5	5	7	8	9	10
		2	0	4	5	6	6	8	8	9	0	3	3	3	6	6	9	9
		3	0	5	6	7	10	11	16	16	0	4	3	3	6	6	9	9
	5	Bundle Size (TEU) Crane Agent No	0	5	5	15	10	20	20	25	0	5	5	15	10	20	20	25
		1	0	1	4	5	7	8	11	15	0	1	1	1	5	6	7	14
		2	0	1	3	5	7	13	15	15	0	1	3	5	6	11	15	15
		3	0	1	10	10	10	11	15	17	0	1	2	10	10	10	10	14
2	1	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	5	8	9	9	9	14	14	0	1	3	3	3	5	13	13
		2	0	1	5	7	8	9	10	10	0	1	4	5	6	8	10	10
		3	0	2	2	6	7	8	9	10	0	2	2	2	4	6	8	10
3	1	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	4	8	8	9	11	11	12	0	1	1	1	3	7	7	9

		2	0	2	4	5	6	7	7	9	0	2	2	2	4	4	5	8
		3	0	2	2	5	8	9	11	13	0	2	2	2	3	5	7	11
	2	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	3	3	5	11	12	12	15	0	3	3	5	7	9	9	15
		2	0	2	4	11	11	12	14	15	0	2	2	2	4	4	8	10
		3	0	1	3	4	8	12	12	15	0	1	1	1	3	9	9	15
	3	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	1	3	6	8	8	9	9	0	1	2	2	6	6	8	8
		2	0	1	6	7	8	11	11	14	0	1	1	3	6	7	7	8
		3	0	1	3	5	8	9	9	9	0	1	2	5	6	8	8	8
	4	Bundle Size (TEU) Crane Agent No	0	11	15	15	26	26	30	41	0	11	15	15	26	26	30	41
		1	0	2	4	13	15	15	16	18	0	2	2	2	5	7	9	12
		2	0	2	3	9	10	11	12	15	0	3	3	3	4	5	7	14
		3	0	2	4	13	15	16	17	18	0	3	2	3	5	8	10	16
4	1	Bundle Size (TEU) Crane Agent No	0	12	12	11	24	23	23	35	0	12	12	11	24	23	23	35
		1	0	1	4	3	10	11	14	15	0	1	1	3	5	7	13	14
		2	0	1	1	2	4	5	10	10	0	1	1	1	2	4	9	10
		3	0	2	3	6	3	6	7	15	0	2	2	3	3	5	5	9
5	1	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	2	3	7	7	9	11	11	0	2	3	3	6	6	7	7
		2	0	4	5	8	8	9	9	11	0	1	3	4	5	5	5	8
		3	0	2	2	5	7	8	8	10	0	1	2	4	5	6	6	10
	2	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	6	12	22	23	25	28	28	0	6	6	14	16	20	26	26
		2	0	7	9	10	12	12	15	15	0	3	5	6	9	9	15	15
		3	0	7	12	15	20	22	24	25	0	3	5	11	15	19	23	25
6	1	Bundle Size (TEU) Crane Agent No	0	3	5	5	8	8	10	13	0	3	5	5	8	8	10	13
		1	0	2	4	7	7	9	9	12	0	1	2	3	3	6	6	7
		2	0	1	3	4	5	5	7	9	0	1	2	2	4	5	5	8
		3	0	1	2	3	5	6	7	8	0	1	2	2	2	4	5	6
	2	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	4	4	5	6	7	8	9	0	2	2	2	4	5	6	8

		2	0	1	2	2	5	6	10	10	0	1	2	2	3	5	5	5
		3	0	2	4	4	4	9	10	10	0	2	3	3	3	8	8	8
	3	Bundle Size (TEU) Crane Agent No	0	16	16	16	32	32	32	48	0	16	16	16	32	32	32	48
		1	0	4	4	5	6	6	9	10	0	2	1	2	2	3	5	8
		2	0	2	2	3	5	6	6	8	0	2	2	2	2	2	6	7
		3	0	3	5	6	6	7	9	9	0	2	2	2	4	5	6	9